Applied Research Laboratory
The Pennsylvania State University

Oak Ridge National Laboratory
U. S. Department of Energy

Development of Advanced Wear and Corrosion Resistant Systems through Laser Surface Alloying and Materials Simulation

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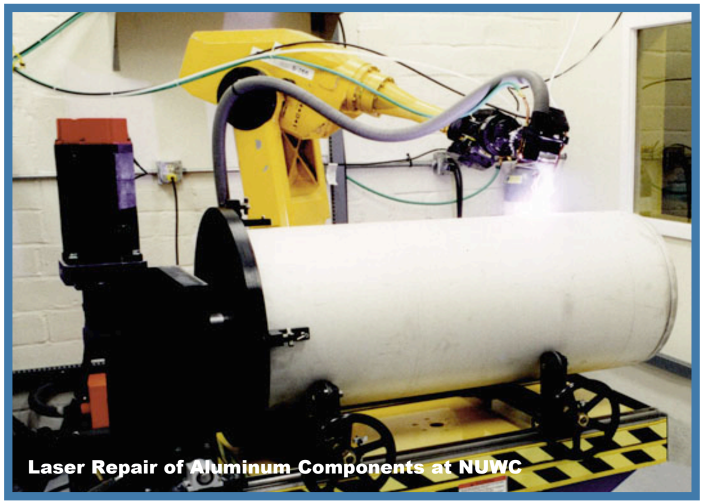
PROGRAM TEAM

- ALSTOM Power Inc., Connecticut and Tennessee
  - wear, fatigue, corrosion, creep and heat resistance surfaces for energy and mining industries
- Praxair Surface Technologies, Pennsylvania
  - wear, fatigue, corrosion, creep and heat resistance surfaces for various heavy manufacturing and energy industries
- Alvord-Polk Corporation, Pennsylvania
  - tooling grade coatings on low cost substrate materials
- Spirex Corporation, Ohio
  - Improved machinery for materials processing
- Applied Research Laboratory's Laser Processing Consortium:
  - development and implementation of advanced laser processing technology for the US Navy and industry
- Oak Ridge National Laboratory
  - development of advanced materials and processing solutions for US industry

Management Contractor for DOE's Oak Ridge National Laboratory

PROGRAM GOALS



Laser Repair of Aluminum Components at NUWC

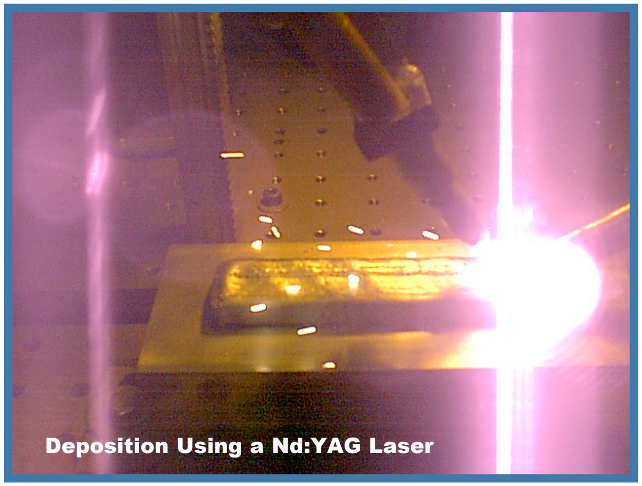
Laser Deposition of Tooling Material at Alvord Polk Corp.

GOALS:

- Develop process and material simulation techniques to identify and develop advanced composite coating systems for laser assisted surface modifications

- Apply these techniques to develop and implement in industry laser-based coating systems that provide improved performance

BENEFITS

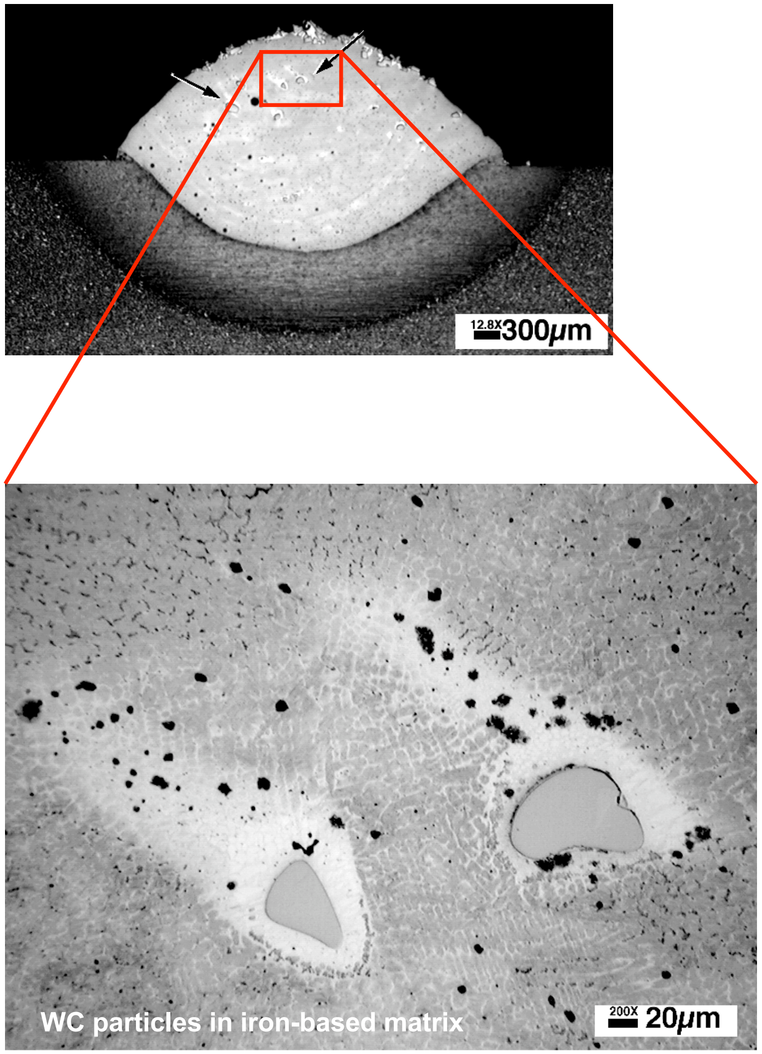


- Laser assisted surface modifications, such as laser surface alloying and cladding, provide:
  - relatively high deposition rates
  - precise control of energy
  - extremely low base metal dilution
  - low thermal distortion
  - refined metallurgical structure
- Hence, these processes offer the potential to provide highly engineered coatings that result in significant improvements in:
  - wear resistance
  - corrosion resistance
  - tolerance for high temperatures

BENEFITS

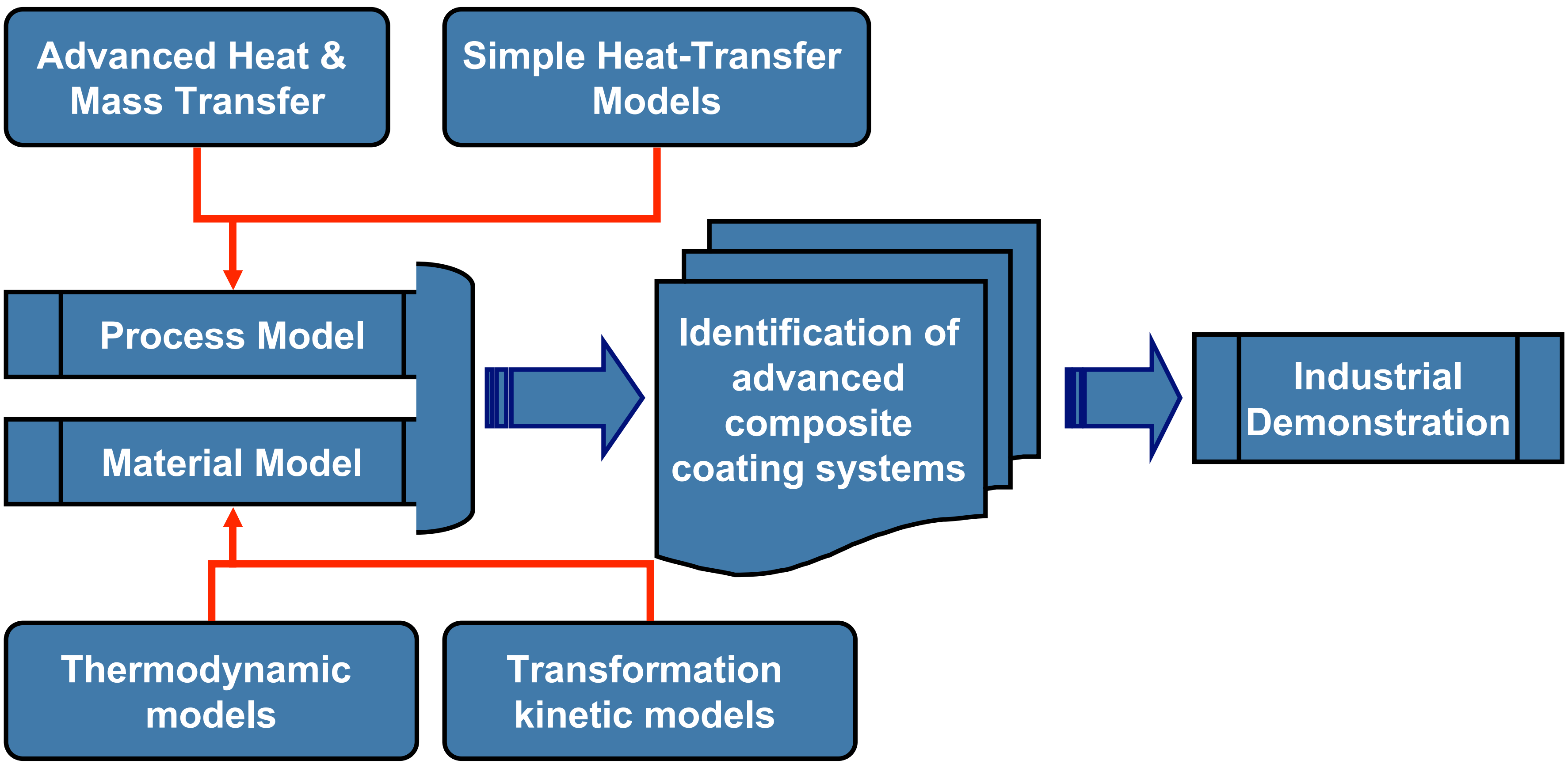
- **Industries of Future:** Components of steel, mining, chemical, mineral processing, agricultural, pulp and paper, foundry and primary metal processing industries with improved wear and corrosion resistance
- **Economic benefit:** Increased performance through life extension, decreased down time, superior wear performance over a wide environmental range and low cost replacement of metallurgical coatings. With 5% applicability and 1% improvement estimated savings for wear and corrosion application is 8.8 million dollars
- **Energy Efficiency:** Improved process efficiency, reduced down time associated with repair and refurbishment of wear and corrosion critical components. Estimated energy savings due to advanced coating technology is 31 million Btu/year
- **Environmental Benefits:** Minimize Cr plating, minimize leaks due to corrosion, minimization of process waste, reduction of scrap due to increased life, recycling with better selection of raw materials, increased efficiency will reduce greenhouse gas emissions

CHALLENGES



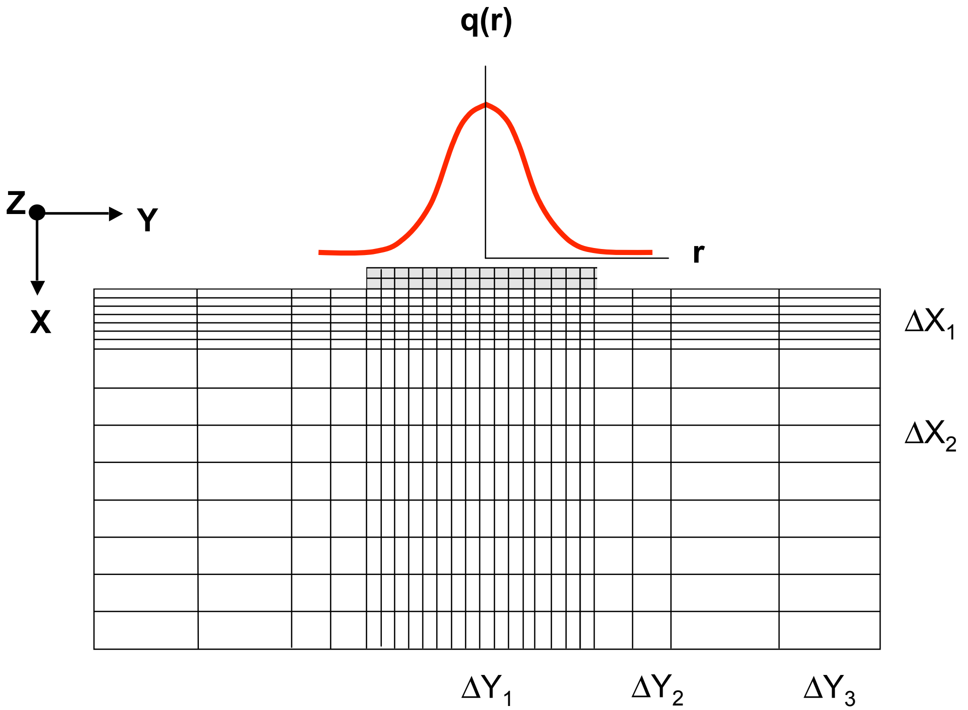
- Improved wear resistance may be achieved through alloy induced transformations, composite hardening, or a combination of both
- However, the challenge is to dictate the evolved microstructures through process development and material design
- Current process and material development has relied on inefficient trial-and-error approach

PROGRAM OVERVIEW

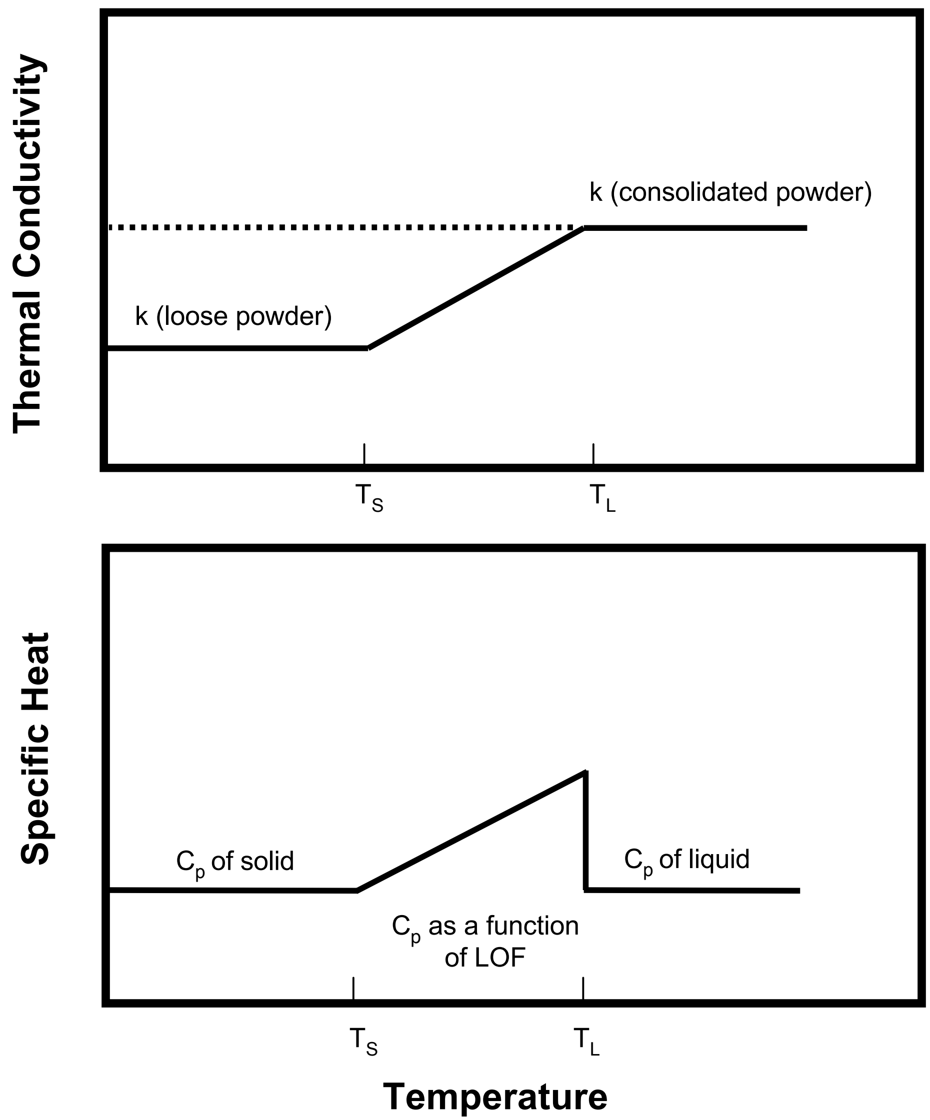


PROCESS SIMULATION

- Three-dimensional numerical model based on explicit finite difference (time-forward central difference form)
- Provides time-dependent (transient) analysis
- Allows for variation in thermophysical properties
  - porous powder layer
  - metallic deposit from powder
  - metallic substrate
- Model can accommodate non-symmetric heating and multiple scans



PROCESS SIMULATION



- **Thermal conductivity (k) is defined as:**
  - **k of the substrate (k_s)**
  - **k of loose powder (k_p)**
  - **k of consolidated powder (k_c)**
- **Thermal conductivity of the powder as a function temperature:**

$$\frac{k_{powder}}{k_{gas}} = V_s N_c \left[2\ln\left(\frac{k_{solid}}{k_{gas}} \right) \right] - 11$$

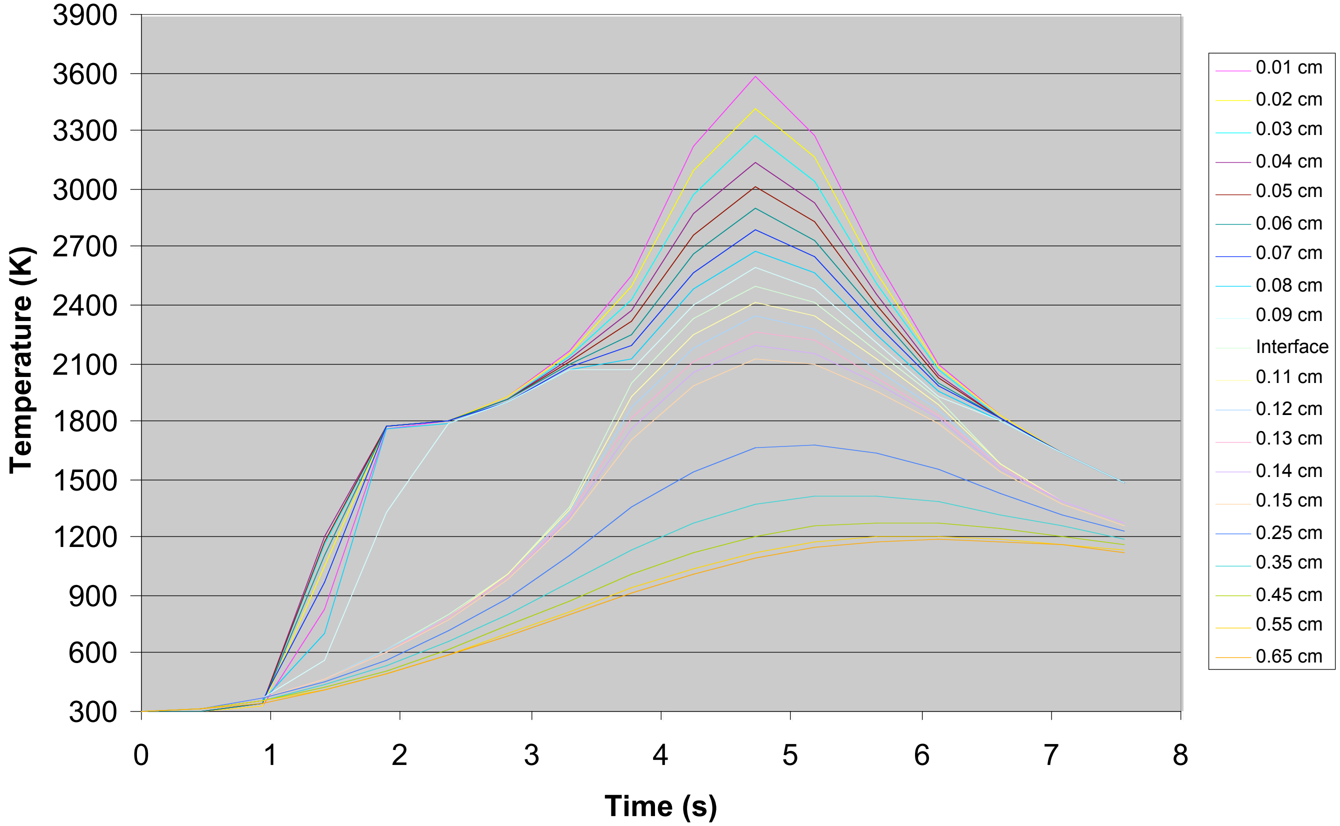
- **Density behaves in a similar manner**
- **Specific heat is used to accommodate for the latent heat of fusion:**

$$C_p' = H_f \frac{(T - T_s)}{(T_l - T_s)} + C_p$$

- **Conservation of energy is evoked at the powder/substrate boundary**

PROCESS SIMULATION

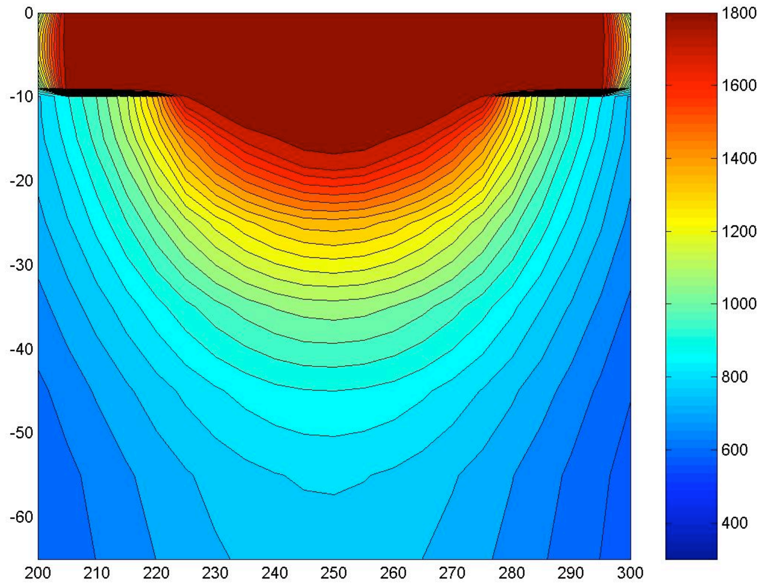
Temperature Versus Time at Various Depths in Deposit and Substrate



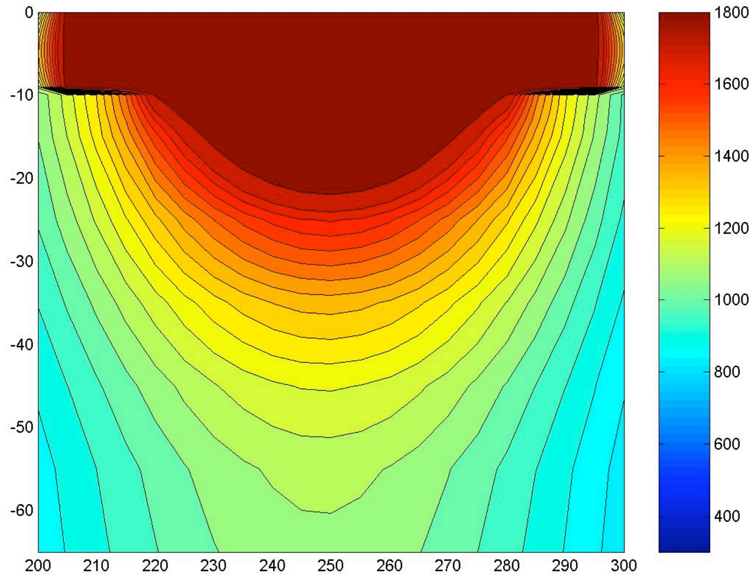
Power = 2430 watts, velocity = 2.12 mm/s, beam diameter = 0.5 mm, powder thickness = 1.0 mm

PROCESS SIMULATION

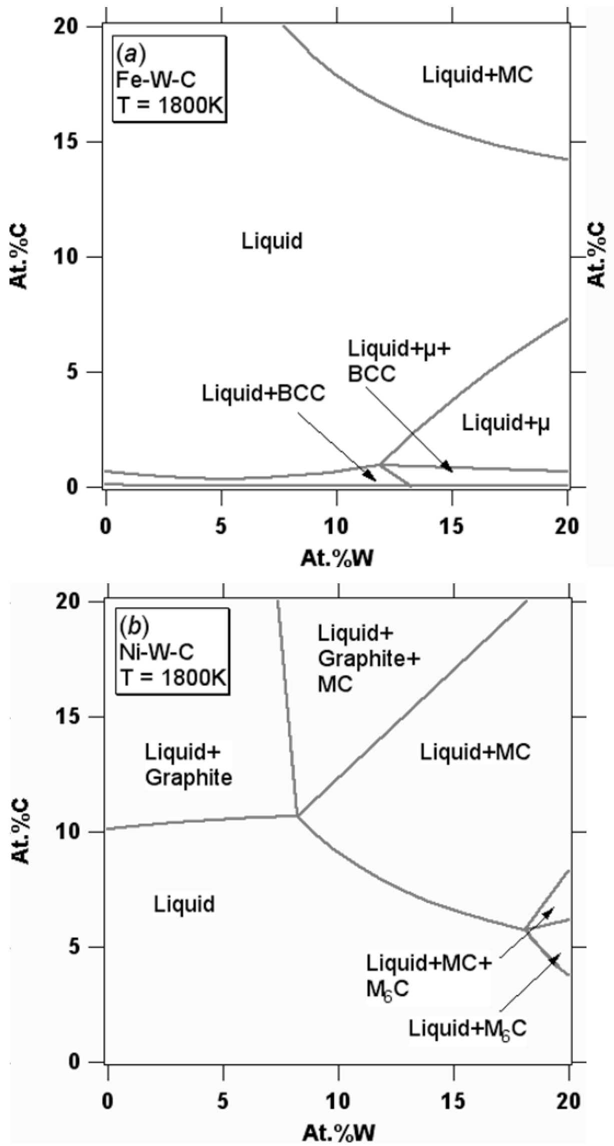
Power = 2430 watts
Velocity = 4.23 mm/s
Beam Diameter = 0.5 mm
Powder Thickness = 1.0 mm



Power = 2430 watts
Velocity = 2.12 mm/s
Beam Diameter = 0.5 mm
Powder Thickness = 1.0 mm



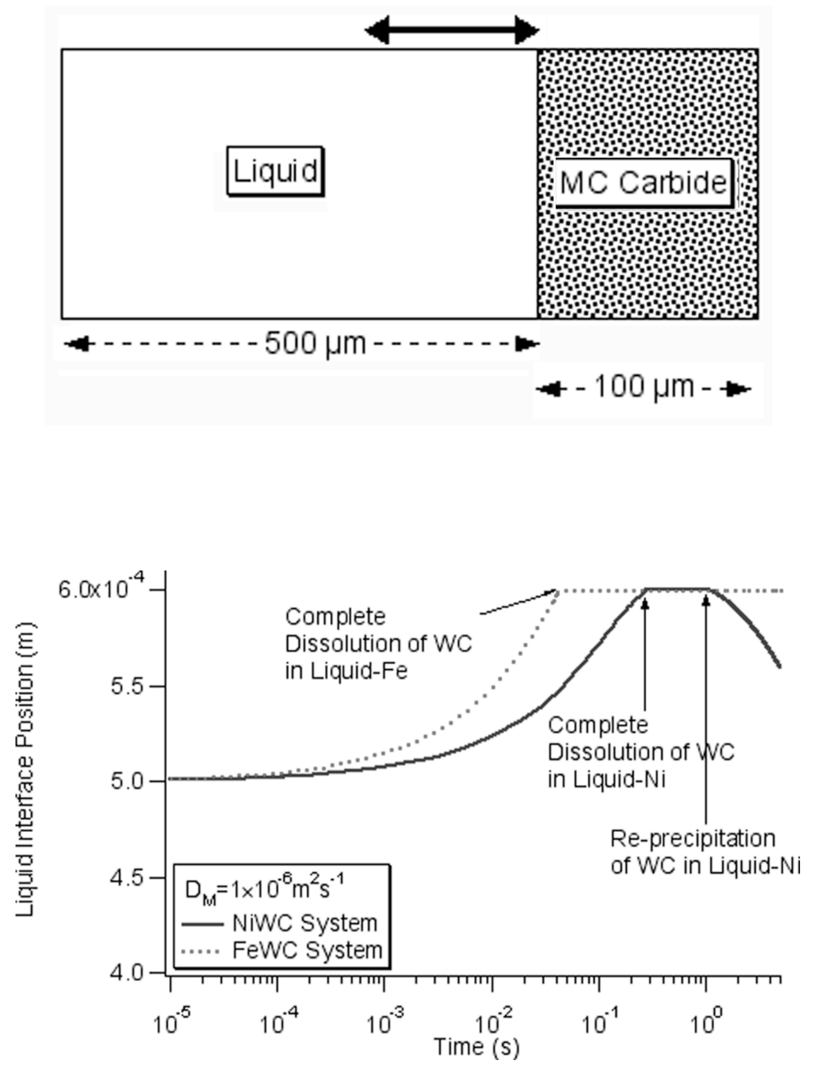
MATERIAL SIMULATION



- **Material simulation is conducted through the use of computational thermodynamics and kinetic analyses under non-isothermal conditions representing the process**
- **Computational thermodynamics provides stability diagrams that are utilized to initially identify composite systems that provide the ability of the hard particles to be retained in various matrix materials**

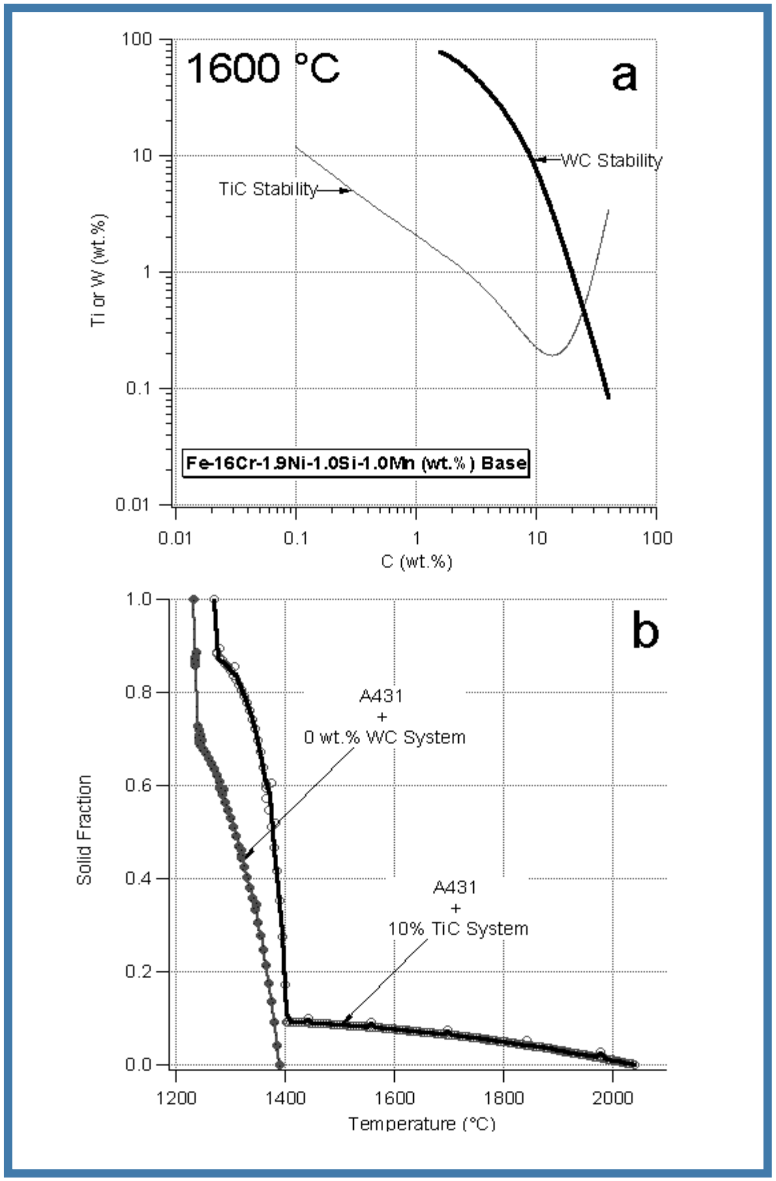
MATERIAL SIMULATION

Materials Models



- **Kinetic calculations consider dissolution and precipitation as a function of thermal cycle and composition**
  - **assumes local equilibrium at the interface**
  - **considers the diffusion in the liquid and rapid thermal cycles**
- **These calculations will eventually be coupled to energy and mass transfer models**
- **The simple kinetic model may also be extended to particle and precipitate arrays**

MATERIAL SIMULATION

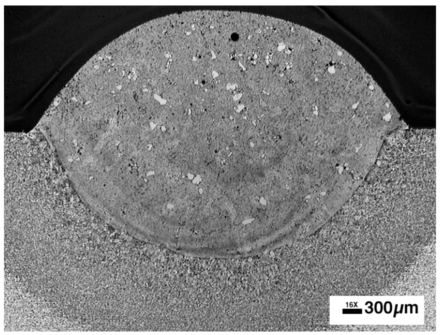


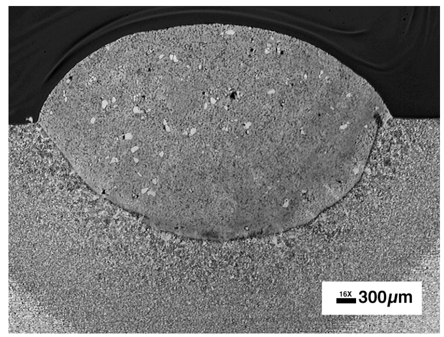
- Material simulations have been used to explain the improved retention of WC in nickel-based matrices over iron-based systems
- It has been used to identified several hard particle systems, such as BN, TiC, and TiN, that should display improved retention in iron-based systems
- The theoretical predictions have been validated by laser experiments utilizing TiC and TiN in iron-based systems

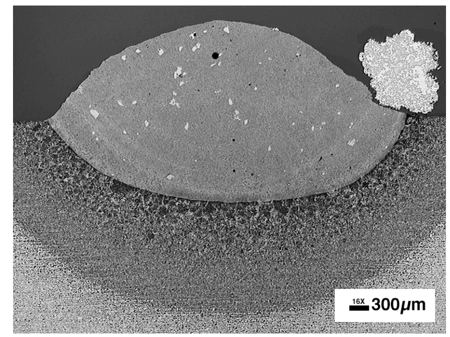
MATERIALS DEVELOPMENT

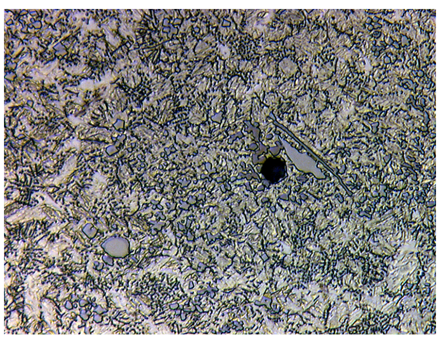
20 w/o TiC in a Martensitic Grade of Stainless Steel (Alloy 431)

20 Ar | 18 Ar – 2 N_2 | Air

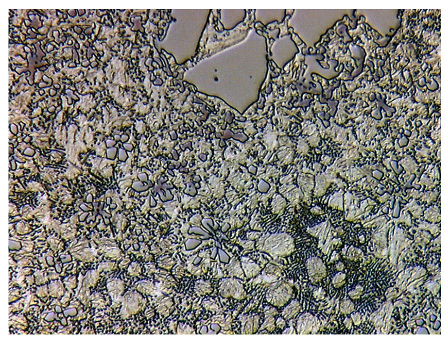




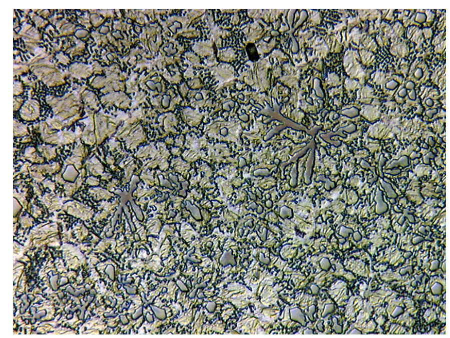




03-1257-XX ARL_ORNL_#7WM 1000X 5μm



03-1256-22 ARL_ORNL_#8 WM(CN) 1000X 5μm

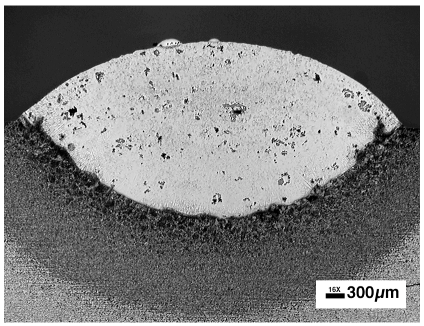


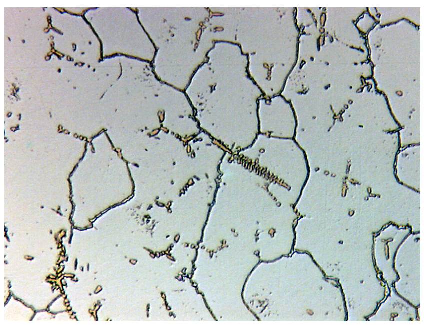
03-1262-09 ARL_ORNL_#14 WM 1000X 5μm

MATERIALS DEVELOPMENT

20 w/o TiN in a Martensitic Grade of Stainless Steel (Alloy 431)

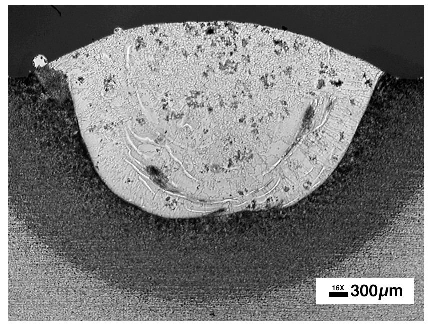
20 Ar

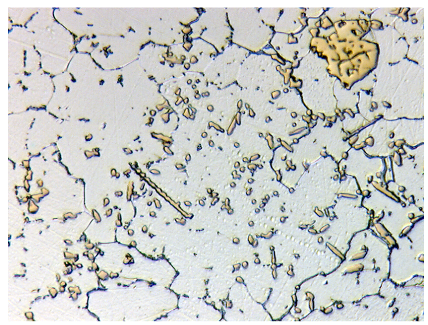




03-1253-09 ARL_ORNL_#4 WM 5μm

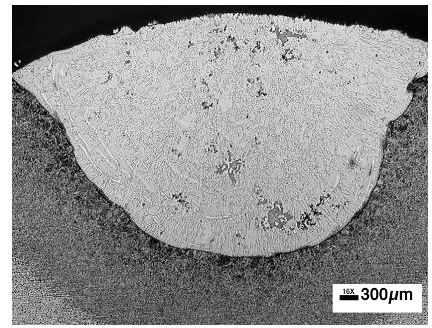
18 Ar – 2 N_2

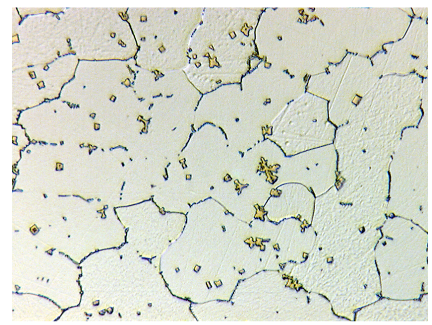




03-1253-23 ARL_ORNL_#5 WM 5μm

Air

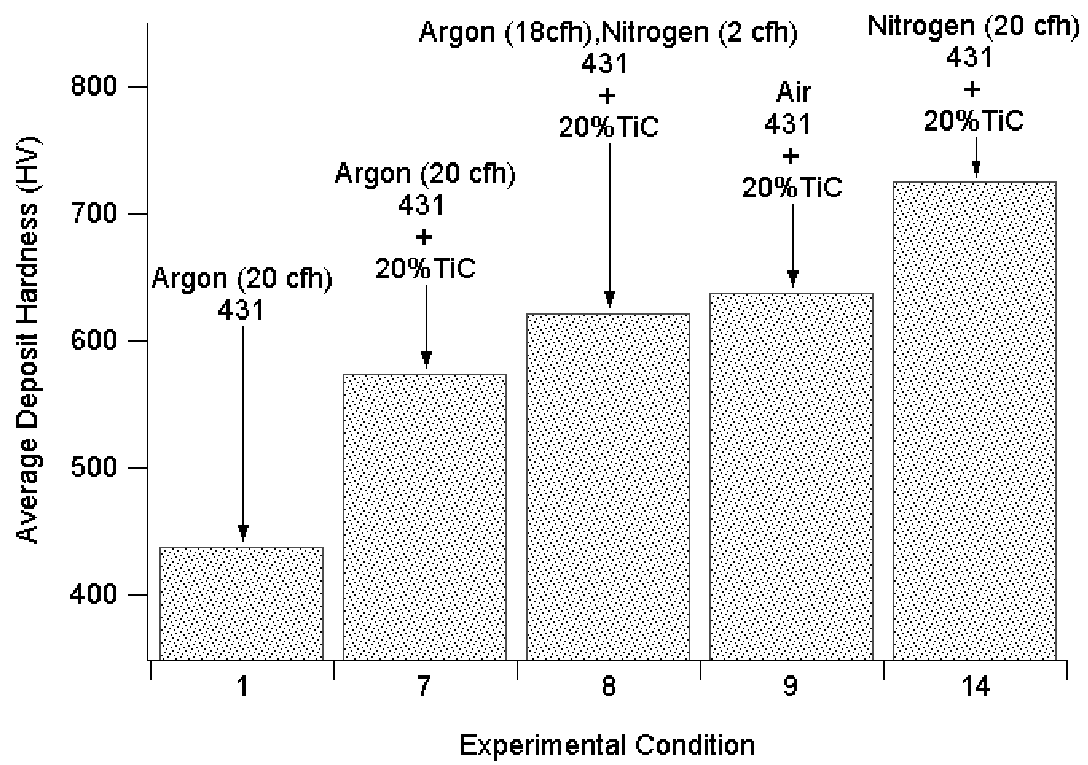




03-1255-07 ARL_ORNL_#6 WM 5μm

MATERIALS DEVELOPMENT

Hardness of SS 431 and 20 % TiC Deposits Using Various Shielding



SUMMARY

- Laser assisted surface modification is a versatile and cross cutting technology that may be used to effectively modify surface properties in metals and ceramics by producing in-situ "composite" microstructures,
- however, due to the complex interaction of the thermal cycle and stability of various phases, composite coating development has generally utilized an inefficient trial-and-error approach,
- results have shown that it is possible through computational thermodynamics and kinetic analyses to theoretically predict the microstructural evolution within the surface modified region, and
- these techniques, coupled with process simulations, are being applied to the development of advanced composite coatings having improved performance characteristics.